Chemical cycles occurring in soil

Round and Round

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Our understanding of the complex processes and mechanisms which occur in various ecosystems is being expanded by a new field of science: biogeochemistry

The progress which the study of ecosystems made in the 20th century enabled us to comprehensively understand only a handful of water-based ecosystems. The reason for this lies in the greater uniformity of water ecosystems compared to those on land. Water ecosystems are also easier to study, and the findings so obtained easier to evaluate and interpret. Developing a more complete picture will nevertheless require more in-depth understanding of soil-based ecosystems.

This necessary research into the complex processes and mechanisms which occur in ecosystems is being advanced by the study of biogeochemical cycles. However, the individual stages in the cycles of myriad ecosystems are characterized by different chemical reaction rates. This especially applies to the circulation of chemical elements which - within the structures of inorganic and organic molecules - make their way from living organisms into inanimate environments and vice versa along specific

The physical and chemical properties of a given soil, which determine its degree of fertility, may encourage the migration of ions and the accumulation of chemical compounds in the soil

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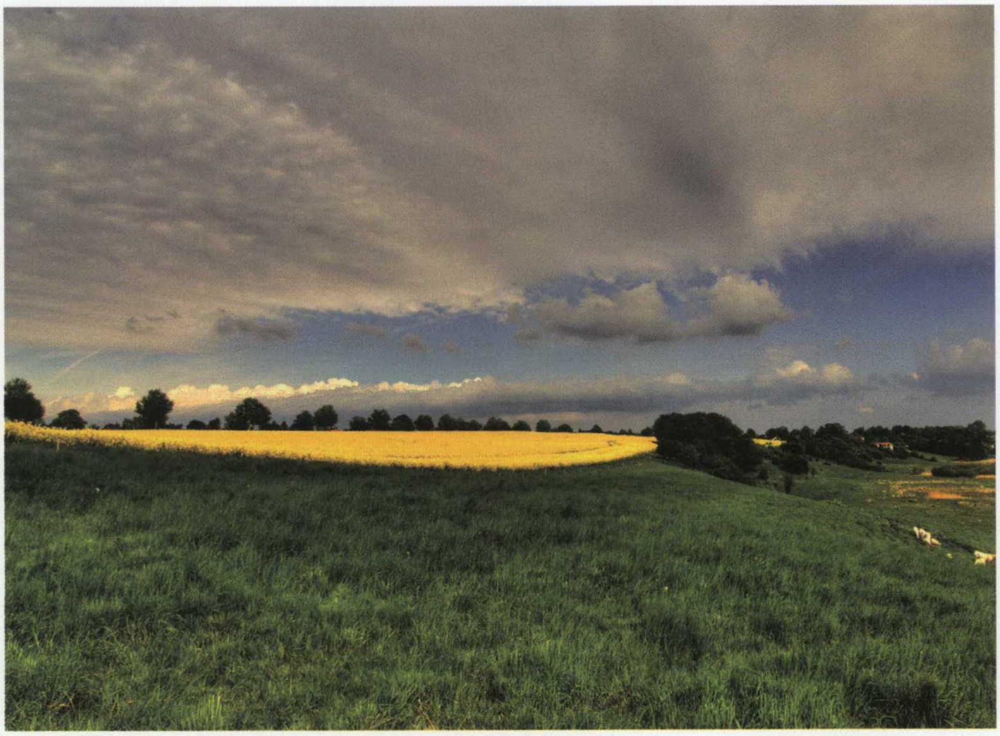

Mid-field shelterbelts play an important role in the migration or halting of mineral and organic compounds which circulate between ecosystems in the agricultural landscape through the groundwater. They help improve groundwater quality and purity

chemical pathways. Mineral compounds and low-molecular weight organic substances transfer from soil to plants, soil organisms, and microorganisms. After those organisms die, the same substances spread back into the soil. This process proceeds via complex transformations and conversions allowing these substances to be reincorporated into biogeochemical cycles. A chemical compound created in soil during the process becomes a substrate for further chemical and biochemical transformations. The advancement of research into the chemical compounds that are in constant circulation in soil has led to the establishment of a new branch of science called biogeochemistry.

Key processes

Biogeochemical cycles only exhibit regularity when the concentrations of compounds in the cycle are close to those contained in soil solutions, known in chemistry as "real concentrations." Where the organic matter in soil is subject to considerable accumulation, sometimes only periodic, a significant slowdown in cycle processes occurs. Lower rates of chemical and biochemical reactions as a consequence of higher compound concentrations are most clearly evident in what is called the "catotelm" or inert layer of peat, which lies 0.5 m under the surface.

The biogeochemical cycles of key importance are the cycles of carbon, nitrogen, phosphorus, sulfur, and also water. Despite the significant progress that has been made in the field of biogeochemistry, these cycles as a whole plus the individual processes they incorporate still remain poorly understood - partly because they occur in ecosystems that are relatively poorly studied, characterized by the occurrence of what are known as secondary cycles. They take place under complex conditions involving links and interactions among several related ecosystems. Another reason for our lack of understanding lies in the as-yet insufficient use of new specific and selective analytical methods in the study of soil chemistry and biochemistry.

Various soil cycles progress at different rates depending on the local geoclimatic conditions, the type of cultivated crops, organic matter content, oxygen content, salinity, and acidity. Nevertheless, existing regularities can be identified within the complex conditions present in soil and similarities can be perceived between chemical and biochemical processes. The best-studied soil cycles are the phosphorous and sulfur cycles. The sulfur cycle in soil can now be sketched with considerable accuracy, accounting for organic compounds containing thiolic, sulphenic, sulphinic, and sulphonic groups and enzyme systems stimulating specific metabolic processes; this cycle is similar to that which occurs in living organisms. The least well-recognized cycle in soil, in turn, is the nitrogen cycle - progress here being hampered by the multiplicity of nitrogen's organic connections occurring in soil organic matter, together with its significant number of gaseous forms and the excessive importance that has been ascribed solely to its inorganic forms.

Cycling between fields

Far from being of solely theoretical import, research on soil cycles is indeed of huge practical significance. A spectacular example can be found in research on the contribution made by shelterbelts (mid-field rows of trees afforestation) to preventing destruction to the agricultural landscape. Popularized in Poland's Wielkopolska region in the mid-19th century by General Dezydery Chłapowski, shelterbelts have proven effective in protecting the agricultural landscape, including by providing wind protection. Slower wind velocities entail slower rates of water evaporation and improve microclimate for agricultural production. Shelterbelts also restrain water erosion, especially surface erosion, and they form very effective biogeochemical barriers, limiting the migration of chemical and biochemical compounds, including fertilizers and pesticides running off of cultivated fields via the ground water. They therefore play an extremely important function, counteracting the spread of what is known as "nonpoint source pollution." All in all, it turns out that the dispersal of mineral and organic components across large areas of the agricultural landscape, including pesticides, is extremely hard to minimize but can be effectively curbed through systems of biogeochemical barriers formed by shelterbelts, grassland buffer strips, and peatlands. Shelterbelts are involved in the migration of mineral and organic compounds which pass between the ecosystems in the agricultural landscape via the groundwater, as well as in halting and holding such compounds.

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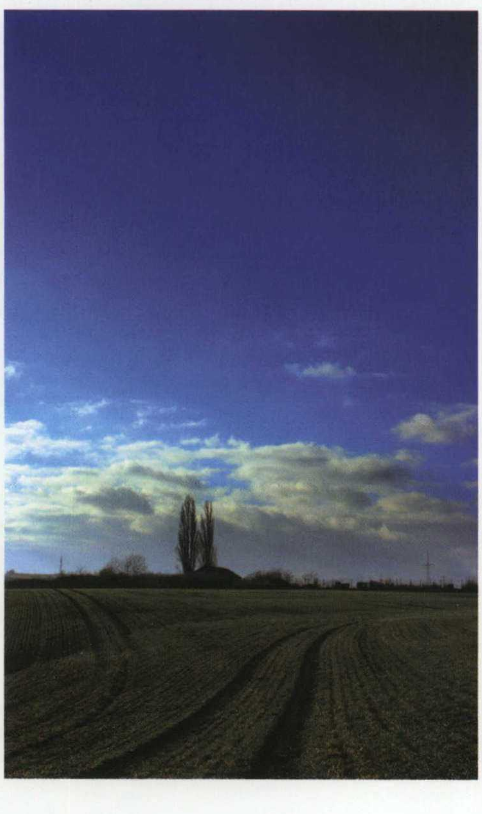

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The properties of humus

To date, several theories have been proposed to explain, in broad outline, why concentrations of such compounds become reduced in the groundwater flowing away from adjoining cultivated fields and passing under shelterbelts. One proposal focuses on the well-developed network of tree roots, which have more groundwater in their range than crop roots do. Due to their 34% greater water transpiration as compared to cultivated plants, trees can also intake nutrients more strongly, thereby affecting the concentrations of chemical compounds in the groundwater. Acting as a kind of lift-and-force pump, tree roots collect mineral and low-molecular organic compounds from their vicinity. These complex processes take place under specific air and water conditions, with the proper redox potential and enzyme involvement. They give rise to humus substances of a specific chemical structure.

The migration of ions via the ground water is thought to be limited by the physical and chemical properties of a given soil, which determine its degree of fertility. Such properties lead to the accumulation of certain chemical compounds in the soil and their absorption by plants. An important role here is also played by the sorp-

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tive complex, representing the colloidal portion of the solid state of soil, together with adsorbed exchangeable ions. The soil colloids which form the sorptive complex are carriers of negative charge, giving the complex a certain cation exchange capacity. An important role in cation exchange sorption is played by humus and clay minerals, although the sorptive capacity of the former significantly exceeds that of the latter. This is due to the greater specific surface area of humus, which adsorbs significant quantities of hydrogen and ammonium ions plus cations of magnesium, calcium, and also heavy metals. Exchangeable cations adsorbed by humus are significantly more easily displaced from the solid state of soil. That boosts their mobility as compared to cations adsorbed by the mineral portion of the sorptive complex.

The import of denitrification

One of the mechanisms involved in altering the form of nitrogen in soils under shelterbelts is denitrification, i.e. the reduction of nitrates and nitrites, leading to the release of gaseous compounds into the atmosphere in the form of N_2O and N_2. The process of denitrification proceeds faster in soils under shelterbelts than in the soil of cultivated fields, due to the greater content of organic matter. That, in turn, makes shelterbelt soils damper than the adjacent cultivated field. Both of these factors give rise to more favorable conditions for the process of denitrification in shelterbelt soils. One negative aspect of this process is the significant loss of nitrogen compounds in the soil.

Shelterbelts decrease the concentration of chemical compounds found in ground waters (nitrites, ammonium ions, total nitrogen, organic carbon, magnesium ions, and calcium ions) by 70%. They thereby help improve the quality and purity of waters. The idea which inspired Gen. Dezydery Chłapowski in the 19th century has therefore gained unexpected new significance in this era of intense agriculture. ■

Various soil cycles progress at different rates, depending on the local geoclimatic conditions

Further reading:

Bendig D.K., Nieder R. (2003). *Handbook of processes and modeling in the soil-plant system.* Food Products Press, The Haworth Reference Press, 762.

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